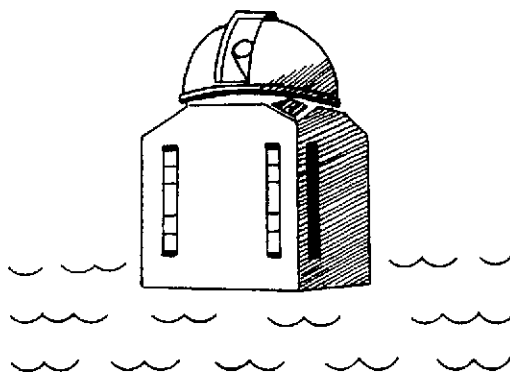
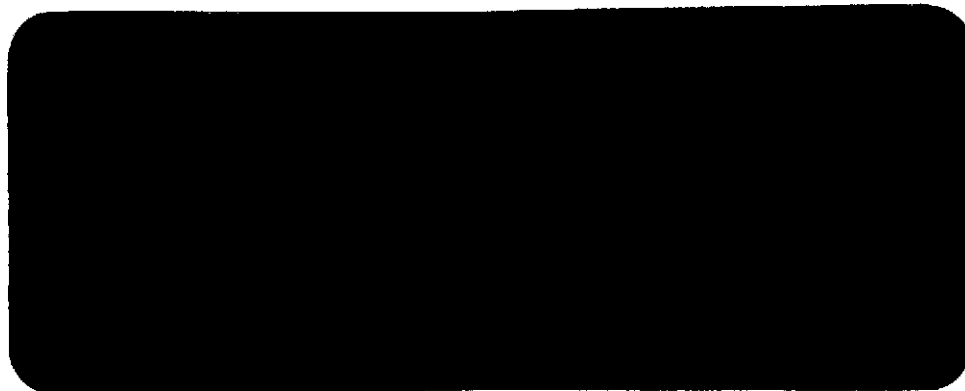


CALIFORNIA INSTITUTE OF TECHNOLOGY

BIG BEAR SOLAR OBSERVATORY

HALE OBSERVATORIES

DRA



(NASA-CR-133848) SUNSPOT MOTION AND
FLARING IN M482 (Hale Observatories,
Pasadena, Calif.) 48 p HC \$3.00

N73-30775

26

CSCI 03B

Unclas

G3/29

15227

SUNSPOT MOTION AND FLARING IN M482

by

B. Lazareff*and H. Zirin
~~~~~

BIG BEAR SOLAR OBSERVATORY, HALE OBSERVATORIES

CARNEGIE INSTITUTION OF WASHINGTON

CALIFORNIA INSTITUTE OF TECHNOLOGY

\*Present Address: Astronomie Solaire et Planetaire  
Observatoire de Meudon  
92 Meudon  
France

BBSO #0130

ABSTRACT

We have studied a series of flares in McMath 11482 August 19-22, 1971, with particular reference to the basis for the flares and comparison with dekameter radio data. We find that the flares were produced by rapid ( $\sim 1000$  km/hr) westward motion of a large new  $p$  spot. Many flares occur just in front of the spot, and they cease when the motion stops. All flares occurring in front of the spot produce type III bursts, while even strong flares elsewhere in the region produce little or no type III. The time of type III emission agrees perfectly with the start of the  $H\alpha$  flare. Thus type III bursts are only produced in favorable configurations.

Simultaneous K-line movies are compared with  $H\alpha$  films and show little difference in flare appearance.

## I. INTRODUCTION

We have studied the evolution of the large sunspot group McMath 11482, that crossed the disk in August, 1972, with particular attention to the types of radio emission produced by different flares and to the connection of a number of flares with rapid sunspot motion in a newly emerging spot. We propose a mechanism by which the motion of this spot produces crossing of transverse magnetic fields (referred to as fibril crossing). There appears to be some relation between the location of flares and the production of type III radio bursts. We have carefully compared our optical flare observations with sensitive swept frequency radio records from the University of Colorado (kindly furnished by Professor J.W. Warwick) which show even very weak bursts in the 7 - 40 MHz range. Almost all flares occurring in front of the moving spot produced strong type III bursts while comparable H $\alpha$  events elsewhere in the region produced no type III emission. The flares producing type III bursts were all accompanied by surges and outward eruptions; and their radio spectra all increase to long wavelength. We compared the movies made simultaneously in H $\alpha$  and the K-line; no substantial difference between the H $\alpha$  and K-line appearance of flares was seen.

## II. HISTORY OF THE GROUP

McMath 11445 was born at the same Carrington position on

# BIG BEAR SOLAR OBSERVATORY ACTIVE REGION DEVELOPMENT

AUGUST 18-23, 1971

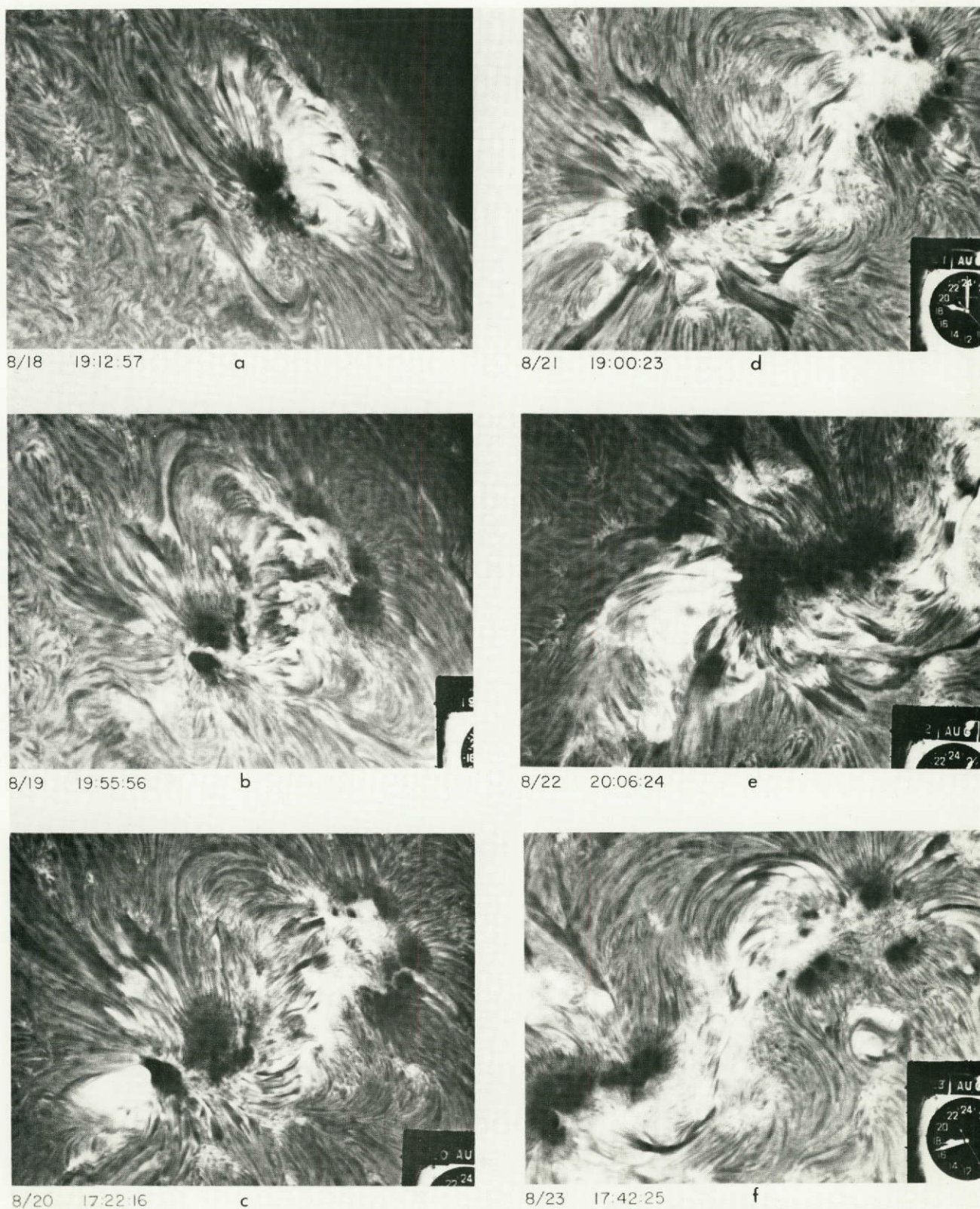


Figure 1

A sequence of H $\alpha$  prints, 8/18 to 8/23, showing the development of the region. Flares are shown on the 8/20 and 8/22 prints. Note now the long train of sunspots follows the lead spot forward. W - left, S - top on all photos.

the preceding rotation but remained small and quiet. McMath 11482 appeared on the east limb on August 17 as a large bipolar group, with a  $p$  spot followed by a bright plage. Most of the activity took place between the 19th and 22nd of August, although there was a later resurgence of activity at west limb passage on the 30th, followed by a proton flare September 1. Figure 1 shows the development of the group in  $H\alpha$  August 18 - 23, while Figure 2 shows a sketch of the sunspots in the critical period August 20 - 22. Table 1 shows the number of flares on each day, showing graphically the activity between the 19th and 24th. The flares up to the 23rd took place mainly in the  $p$  part of the group, while those after this time took place in the following half.

TABLE 1

|                  |    |    |    |    |    |    |    |    |    |    |
|------------------|----|----|----|----|----|----|----|----|----|----|
| Day (August)     | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| $H\alpha$ Events | 5  | 17 | 27 | 31 | 32 | 23 | 15 | 5  | 11 | 14 |
| X-ray Events     | 3  | 2  | 4  | 1  | 4  | 2  | 1  | 1  | 0  | 1  |

The region appeared on the limb in bipolar form, with a bright  $H\alpha$  plage following and a dominant  $p$  spot; off-band photos showed many Ellerman bombs, indicators of new emerging flux. The main spot split on the 17th; on the 18th the southern part of the region was covered by an intense emerging flux region (EFR), the  $p$  spot of which grew rapidly and

4-A

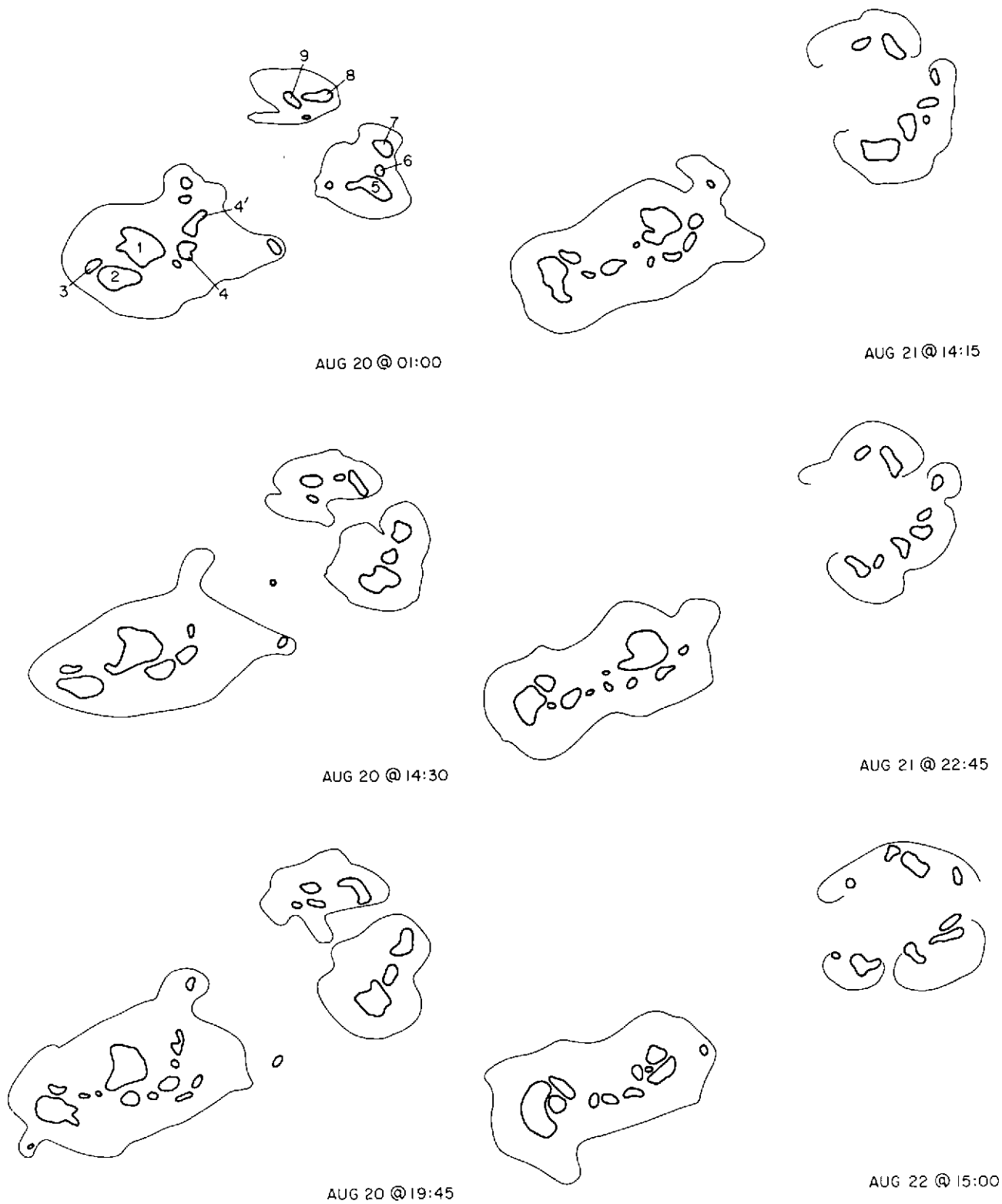


Figure 2

Drawings of the sunspots (based on  $H\alpha$  off-band pictures) during the critical period, August 20 to 22; the spots are all numbered in the first drawing.

moved forward around the old p spot. A substantial flare filled the EFR at 23:43 on the 18th, producing a type III emission. By sunset on the 18th the new spot (marked 2 in Figure 2) was already large.

### III. DEVELOPMENTS AUGUST 19

On the 19th spot 2 had moved rapidly forward, while spot 1 did not move at all relative to the following spots. The drawings in Figure 2 show the relative orientation of the spots. On the 19th, spot 2 was just below (north of) spot 1. On the 20th at 01:00 (see Figure 2) spots 2 and 3 had moved slightly west, and the motion of spot 2 continued at least until the 21st at 15:30. Note how:

- spot 3 was pushed aside and back of spot 2 by the flow.
- spots 4, 4', etc. were drawn behind spot 2 and past spot 1.
- spot 1 was sheared (20th at 14:30) and torn away later by the material being drawn past it.

The motion of spot 2 was due west, with velocities as follows:

|                               |            |
|-------------------------------|------------|
| 19th at 18:30 - 20th at 15:15 | 1100 km/hr |
| 20th at 15:15 - 21st at 01:15 | 1500 km/hr |
| 21st at 01:15 - 21st at 15:30 | 750 km/hr  |

After the 21st at 15:30, spot 2 did not move appreciably, but spot 4 continued its motion (see 21st at 22:45) and ended up against spots 2 and 3, while spot 1 began to break up.

Although the x-ray flares on the 18th and 19th occurred

in the middle of the EFR, after the rapid motion of spot 2 began, almost all flares in the region occurred either just preceding spot 2 or around it until the rapid motion stopped. Furthermore, all type III bursts came from this region. There was a very bright, continuously active plage at the front (west) edge of spot 2, out of which all these flares grew and blew off to the west.

The film on August 19 shows almost continuous activity. Two homologous flares occurred just behind sunspot 2 at 16:00 and 18:35 (the latter is illustrated in Figure 7a). Both were tightly contained, the first produced soft x-rays and a small centimeter burst (7.4 sfu at 9400) and the second produced soft x-rays and an SFD, which indicates the emission of hard x-rays (Kane and Donnelly, 1971) but no centimeter burst was recorded. The first produced no type III, the second a very weak burst. By contrast, a large eruption of chromospheric material just ahead of spot 2 at 17:15 produced intense type III emission, but no centimeter emission. In this case the H $\alpha$  intensity was low and the K-line even less, but a great number of flux loops erupted outward. Although x-ray observations for that event are not available, there was no SID reported, thus x-ray emission must also have been small. We cannot explain the absence of cm radio emission from the 18:35 event, particularly because there was an SFD. Another small bright flare in the following part at 18:10 also produced nothing. However, the pattern of these three flares is clear; the two well-contained flares produced x-rays and

some centimeter emission but could not produce exciters of type III bursts, whereas the outward erupting material ahead of the new sunspot produced large type III, but could not contain electrons for centimeter wave emission.

The Solrad 9 data for the 18:35 flare showed a curve of x-ray emission closely similar to H $\alpha$ , with rise time 1 minute and decay time 3 minutes. The maximum 1 - 8 Å emission was  $3.5 \times 10^{-3}$  erg/cm<sup>2</sup>/sec, between 18:37 and 18:38. Optically, the two tightly contained flares occurred in the arch filaments behind spot 2. At 18:30 the loop was already brighter than the surrounding region, and at 18:35:45 the two sides of the loop brightened rapidly, reaching maximum at 18:37. H $\alpha$  emission then decayed and returned to the initial level around 18:40. We doubt that the absence of centimeter emission is observational: it is more likely that the flare is so low that the emission was reabsorbed at all frequencies. Note that the plasma frequency reached  $9 \times 10^9$  Hz when  $N_e = 10^{12}$ . However, at the same frequency, at  $T = 10^4$  K,  $N_e = 10^{10}$ , free-free absorption is  $2 \times 10^{-7}$  cm<sup>-1</sup>, so that the optical depth exceeds one in one scale height. It thus may be that free-free absorption is the limiting factor at that frequency (Ramaty and Petrosian, 1972).

The 16:30 flare was quite similar, with  $5 \times 10^{-3}$  peak x-ray flux in 1 - 8 Å, but radio emission was detected at Huancayo: 7.4 sfu at 9400 MHz. The preceding discussion on radio absorption and the fact that 3 cm emission was just detected allow us to locate these flares around  $N_e = 10^{10}$

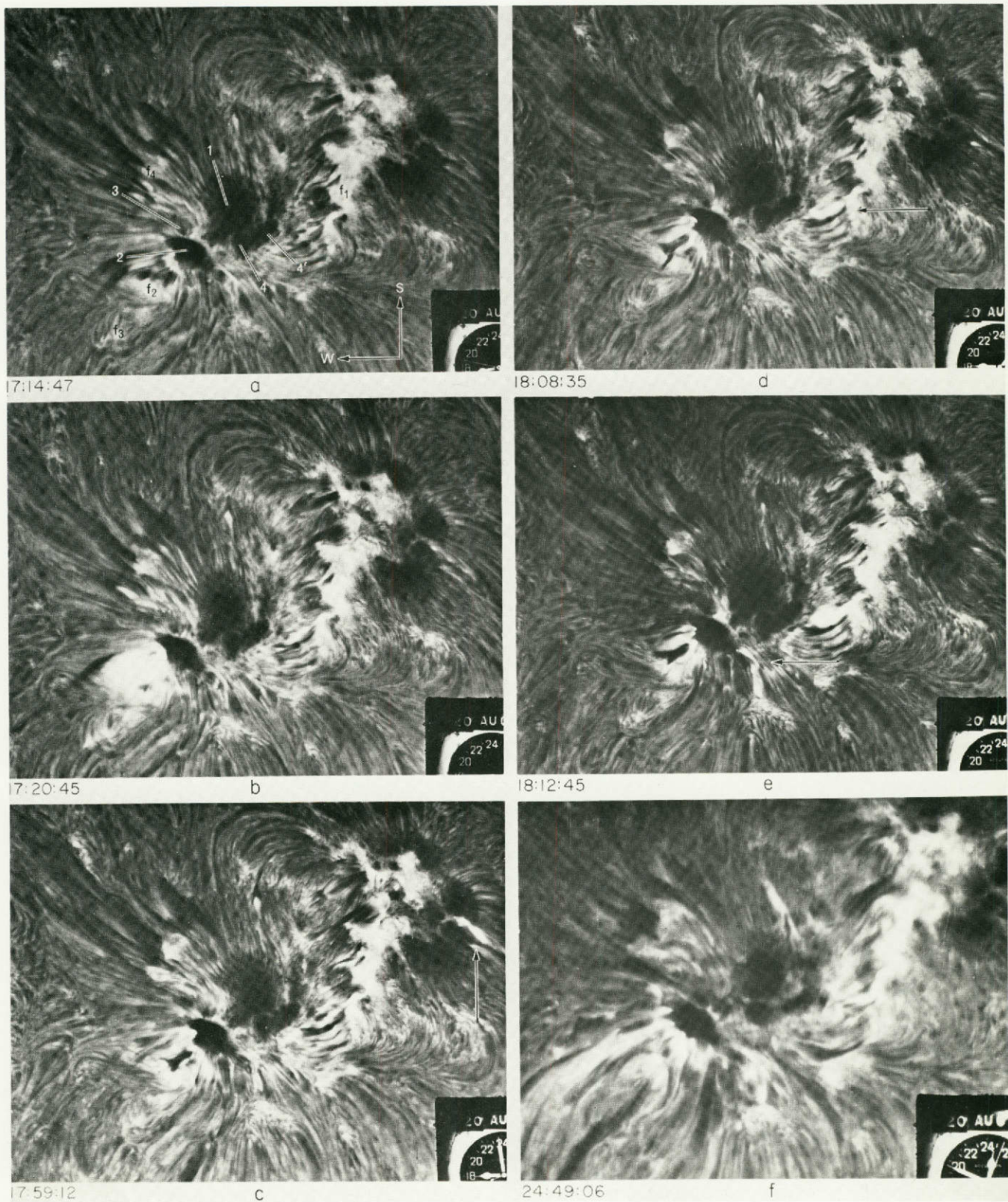


Figure 3

A series of prints of events on August 20. In (a) the different plage and spots are marked, and in (c), (d) and (e) arrows mark connected flares in an apparently causal sequence.

(surrounding material). The actual height is model-dependent.

To conclude, these flares show: (1) plasma confinement preventing dekameter emission; (2) in the 18:36 flare, hard x-rays without cm emission, i.e. an exception to a commonly accepted rule.

#### IV. THE FLARES OF AUGUST 20 AND 21

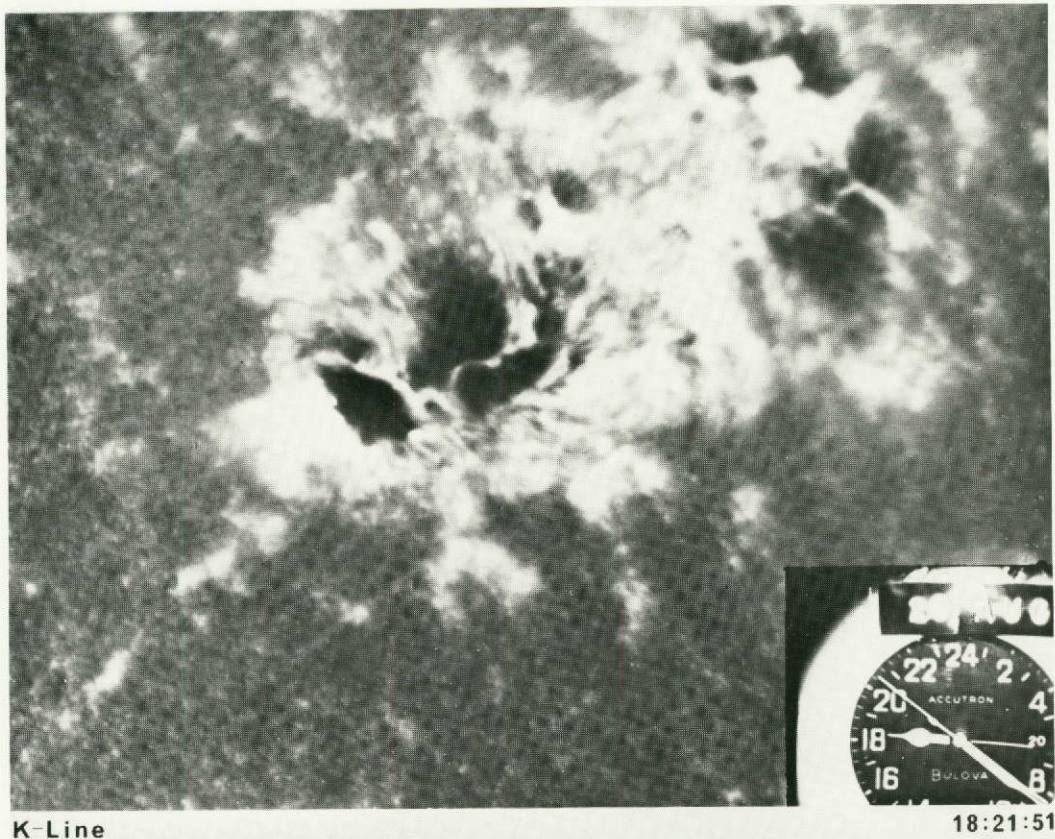
By the 20th (Figures 1 and 2), the new  $p$  spot (2) was as large as the old (1) and had moved around ahead of it. A bright rim on the edge of the new spot was the source of a series of flares which were particularly prolific in producing type III bursts. Presumably, the occurrence of these flares was due to the motion of the new spot 2 and bunching and twisting of field lines produced by this motion, as shall be explained below. All these flares produced great surges and eruptions following arched field lines connecting ahead of the group to  $f$  polarity just outside the frame. Further, all the flares came from the edge of the umbra; no emission was ever seen over the umbra, although it could have easily been detected if present.

The Mount Wilson magnetogram on the 19th shows a plage of  $f$  polarity just west of spot 2 with a field between 10 and 20 gauss, and a steep gradient between these. In the absence of higher resolution magnetic observations, we identify this with the plage  $f_2$  just W (left) of spot 2 (Figure 3a), connected to it by short dark fibrils. This is, of course,

characteristic of newly emerging flux, and may either be flux accumulated by the motion of the spot, or more likely a new EFR being overrun by the rapidly moving sunspot 2. In any event, most of the flares of the 19th and 20th started in this small region. The first flare on the 20th at 17:16 (Figure 3b) began with brightening in the EFR, appearing to spread outward from the spot 2 along the short dark fibrils. A bright surge flowed out along overlying field lines that returned to the surface somewhere outside the frame, but an over-exposed frame at 17:22 shows the brightest part of the flare still to be the area of the EFR. The maximum of H $\alpha$  brightness occurred at 17:20 simultaneously with a cm radio maximum, a soft x-ray burst, and an SFD, indicating hard x-rays. The first intense type III burst at 17:18:30 was simultaneous with the most rapid increase in brightness. A long dark surge was continually present after 17:15. The K-line film shows the edge of spot 2 is continuously bright and shows continuous activity.

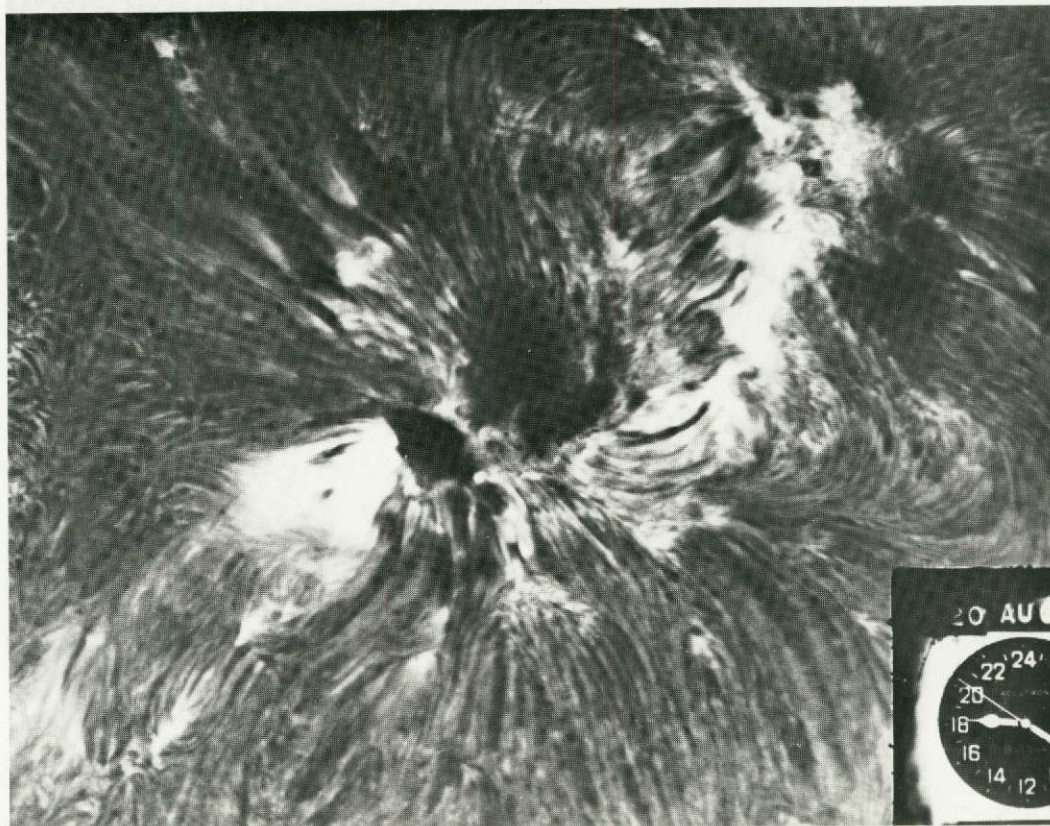
A second flare, at 18:18 was similar, but had a slower rise with no cm emission and slightly less x-ray emission. It appeared to be triggered by a propagating disturbance evidenced by a sequence of four localized brightenings (see Figure 3c, d, e). These were:

- (1) a small flare in the following half of the group at 17:59 (arrow, Figure 3c),
- (2) a bright flare in the FTA region, starting 18:08 (arrow, Figure 3d)



K-Line

18:21:51

H $\alpha$ 

18:21:51

Figure 4

Simultaneous H $\alpha$  and K-line (1.2 Å bandwidths) pictures of the 18:22 flare. If the K filter is set at 0.3 Å, dark fibrils may be seen, but the exposures become very long. Note the bright areas at lower left produced by dumping of flare particles.

(3) a small brightening NE of spot 2 at 18:12 (arrow, Figure 3e).

(4) a bright flare W of spot 2 starting at 18:14 and quiet similar to 17:22.

The last is the flare, shown in  $H\alpha$  and K in Figure 4. It produced a continuous long dark surge, which is shown in Figure 5 to the blue of  $H\alpha$ . Although the surge only appeared to move around 100 km/sec, rapid waves of excitation are seen to move outward through the surge. Also, two bright areas appear in the chromosphere to the west of the surge, apparently produced by a wave of brightening, moving out at 500 km/sec. Surprisingly, within a minute after the flare, material began moving rapidly inwards along the surge while other matter was still flowing rapidly outward. The time and distance spacing in the sequence leading to the 18:14 flare are consistent with the propagation of a disturbance (not visible in  $H\alpha$ ) travelling at about 160 km/sec. The a priori probability of such a sequence is small, and we think that the phenomenon is real. The bright tightly-contained flare (Figure 3e) began at 18:06, maximum at 18:09, in the center of the region and produced a soft x-ray burst, but no cm emission and a single weak type III burst at the onset; it was considerably smaller than the 18:14 flare. The last flare produced a big type III burst at 18:18. Both the 17:20 and 18:18 events produced SFD's, a measure of hard x-rays. Later in the day observations were interrupted by clouds, but showed a flare at 19:43 along the whole area preceding spot 2, followed by a rising arch

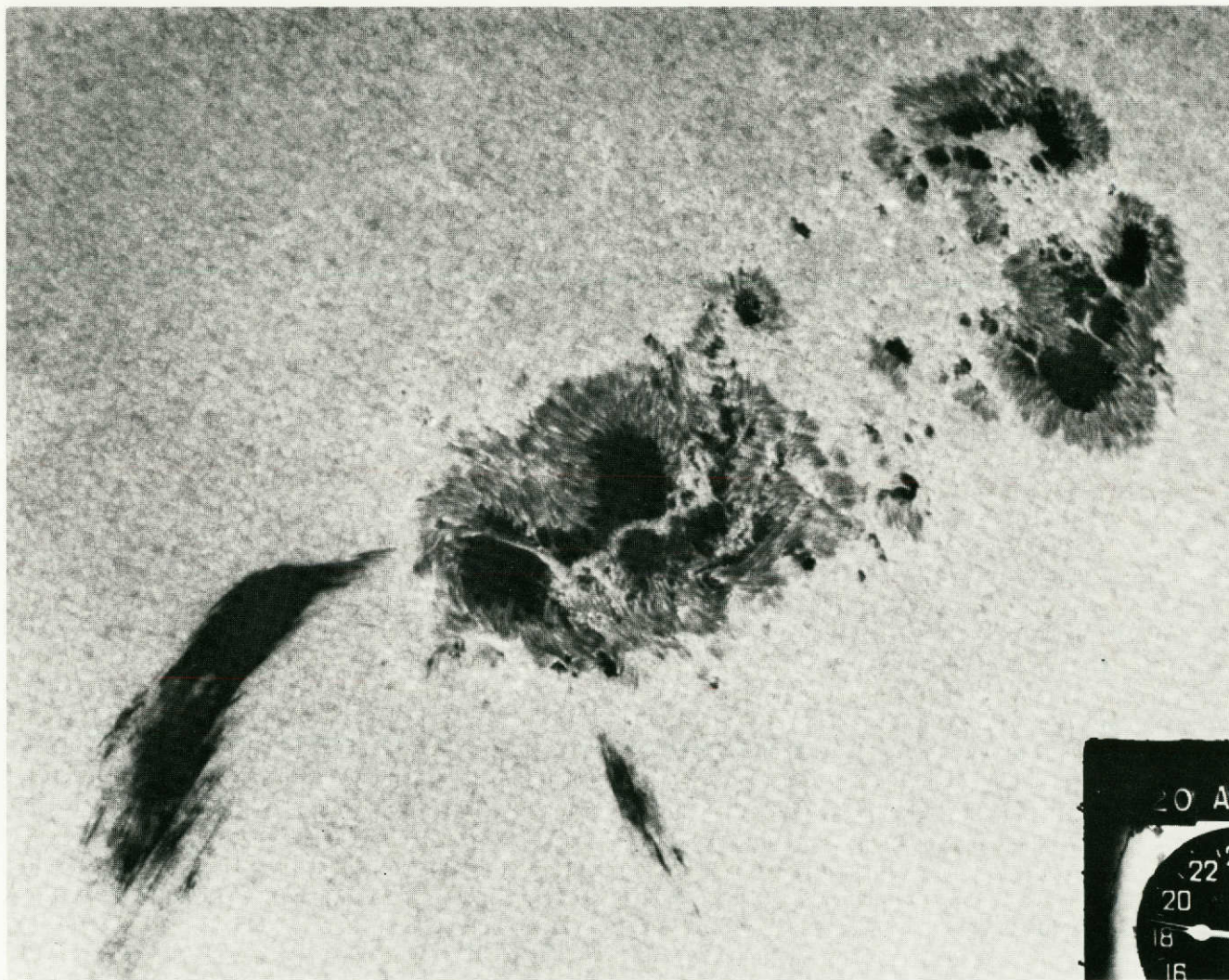


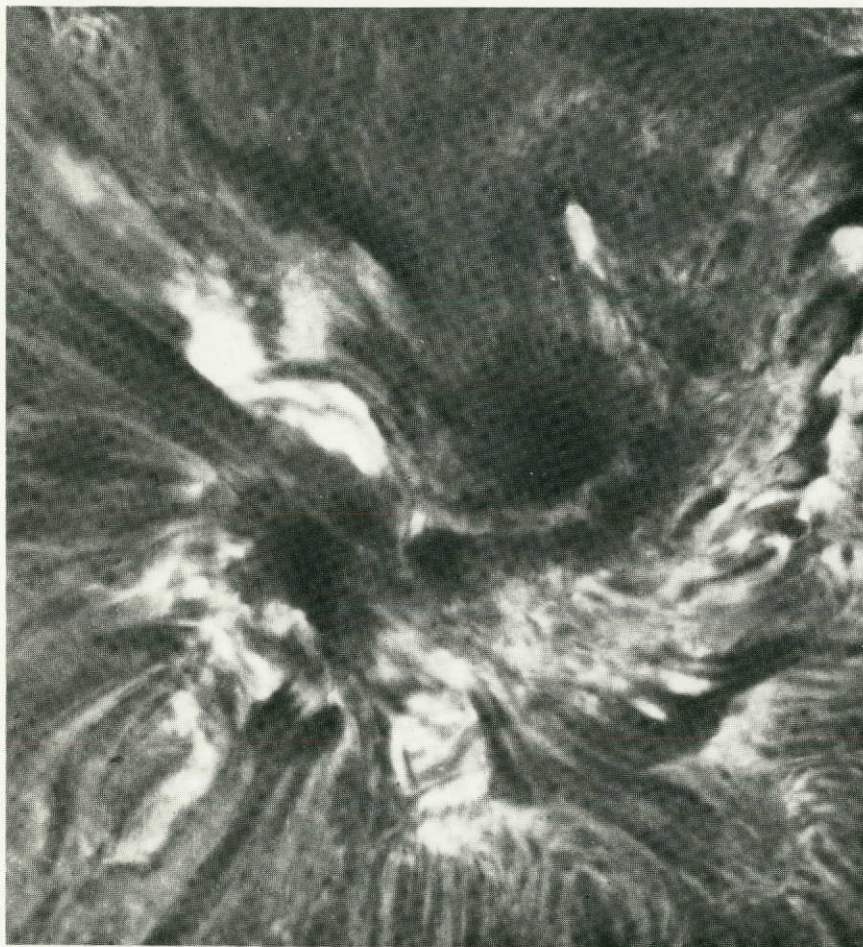
Figure 5

Photo at  $H\alpha - 2 \text{ \AA}$ , 18:25:45 U.T., 8/20. The main surge is nicely visible thanks to its Doppler shift; and a smaller simultaneous surge to the north (below) is also seen. A number of Ellerman bombs are seen in various places. Note the sharply sheared penumbral structure along spot 2 and in the area of the 18:08 flare. Such sheared penumbrae, with fibrils parallel to the edge of the umbra rather than radial, are typical flare-producing structures and presumably caused by the spot motion.

and two intense type III bursts. A fine bright surge in a different area south of the spot at 21:06 gave no radio emission despite much outward motion; but brightenings ahead of the spot 2 at 20:32 and 21:53 again produced intense type III emission. Although the flares ahead of spot 2 were obviously the largest, we found type III bursts connected with even very weak brightenings there, whereas none of the other flares in the region produced bursts. It would appear from this that containment is not the principal factor, but that the region in front of the spot 2 was very favorably situated for the acceleration and emission of the electrons responsible for type III bursts. The times of the type III bursts invariably agreed (to within 15 sec) with the times of the  $H\alpha$  flashes (steepest rise), implying that the energetic electrons are produced right at the start, and that the  $H\alpha$ , which lasts 5 or 10 minutes longer, represents the later evolution.

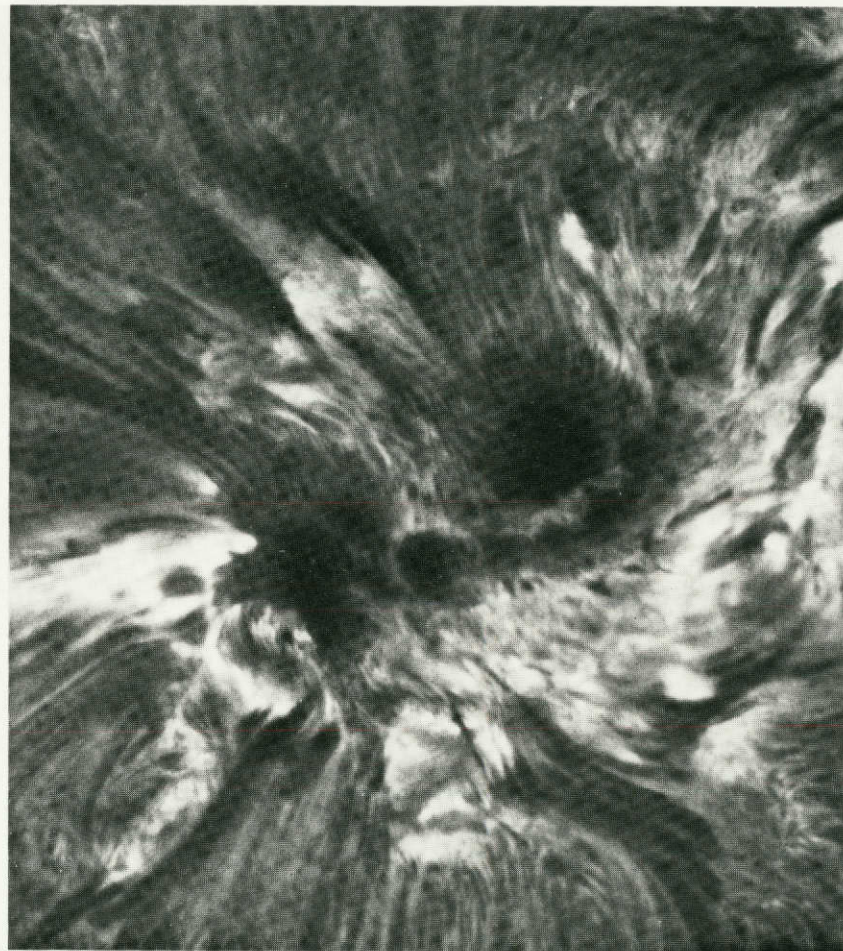
In all, fifteen brightenings or flares were observed this day in front of spot 2, all of which produced type III emission, twelve of which were intensity 2 or 3. There were four flares in other places in the spot group, which produced one burst of imp 2 at 22:21, and only very weak bursts otherwise.

By the 21st, the spot 2 had moved about 15,000 km ahead of spot 1, and flares continued from the west edge of the spot. At least ten similar small flares were observed at this point, all of which produced intense type III bursts, along with no soft x-rays, and slight cm emission. Again, various flares



8/21

16:26:12



8/21

18:21:07

Figure 6

Two flares on August 21

16:26:12, wrong place, no type III.

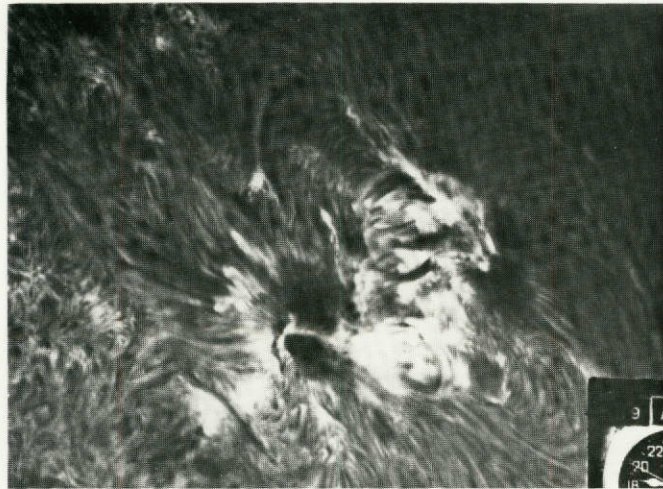
18:21:07, right place, large type III.

at other points in the region produced soft x-rays or cm emission, but no type III bursts. The flares appear to occur in a region across the magnetic fields ahead of the spot 2. Figure 6 shows 2 flares, one at 16:26:12 in the unfavorable region S of spot 2, which gave no type III, and one at 18:21:07 from spot 2, which gave a big type III burst.

## V. FIBRIL CROSSINGS AND FLARES

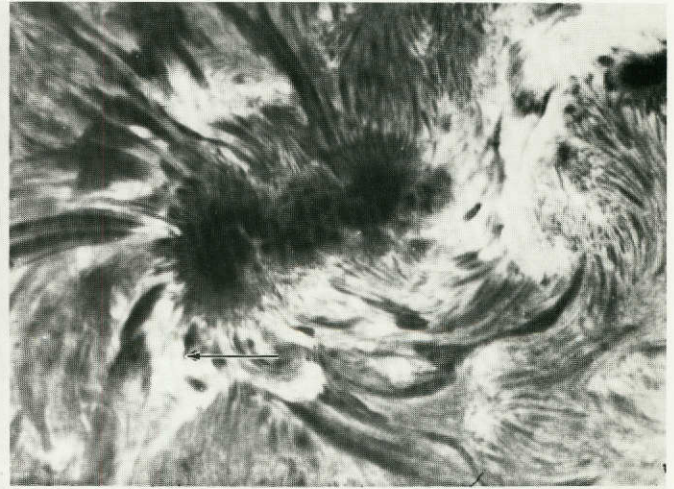
The flares in front of spot 2 all occur in regions of crossed fibrils, and several are seen to brighten simultaneously in two crossed fibrils. One connects spot 2 with the small  $f$  inclusion, and the other, also starting from spot 2, but reconnecting much farther, and crossing the first at a right angle. Although it is not clear from the  $H\alpha$  picture, we assume that the second fibril goes over the first. We suggest the following mechanism to create such a configuration:

When a sunspot, such as 2, plows its way through the photosphere at a velocity of  $1000 \text{ km/hr}^{-1}$ , the ram pressure  $p.v^2$  at the base of the chromosphere is  $16 \text{ dyne/cm}^{-2}$ , which is the magnetic pressure corresponding to a field of 20 g. Going down a few scale heights, much stronger fields can be pushed around by the fluid motion. Let us now suppose that the sunspot is connected to nearby small inclusions of opposite polarity. We have the following discussion, in a reference frame where the sunspot is at rest, and the surrounding material flowing past it. (See Figure 7.) Evidence from coronal structures



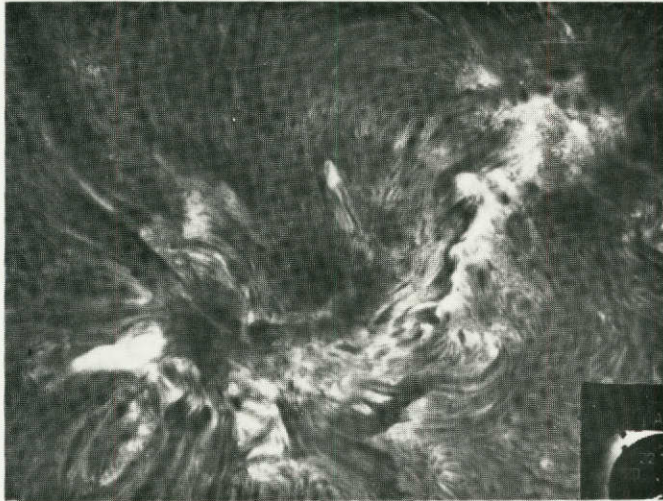
19 @ 18:36:50

a



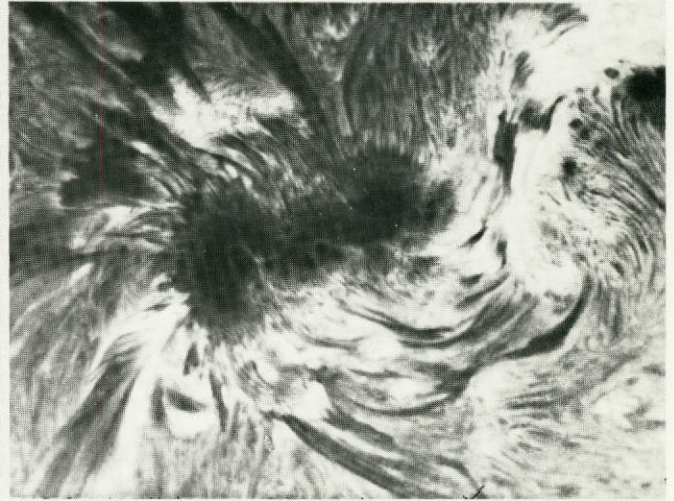
22 @ 20:20:00

c



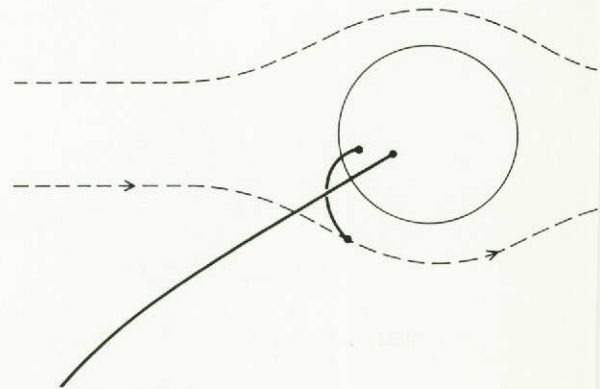
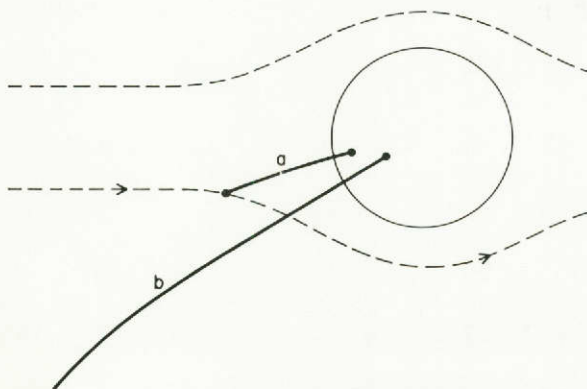
21 @ 16:21:00

b



22 @ 20:36:25

d



PROPOSED MECHANISM FOR FIBRIL CROSSING

Figure 7

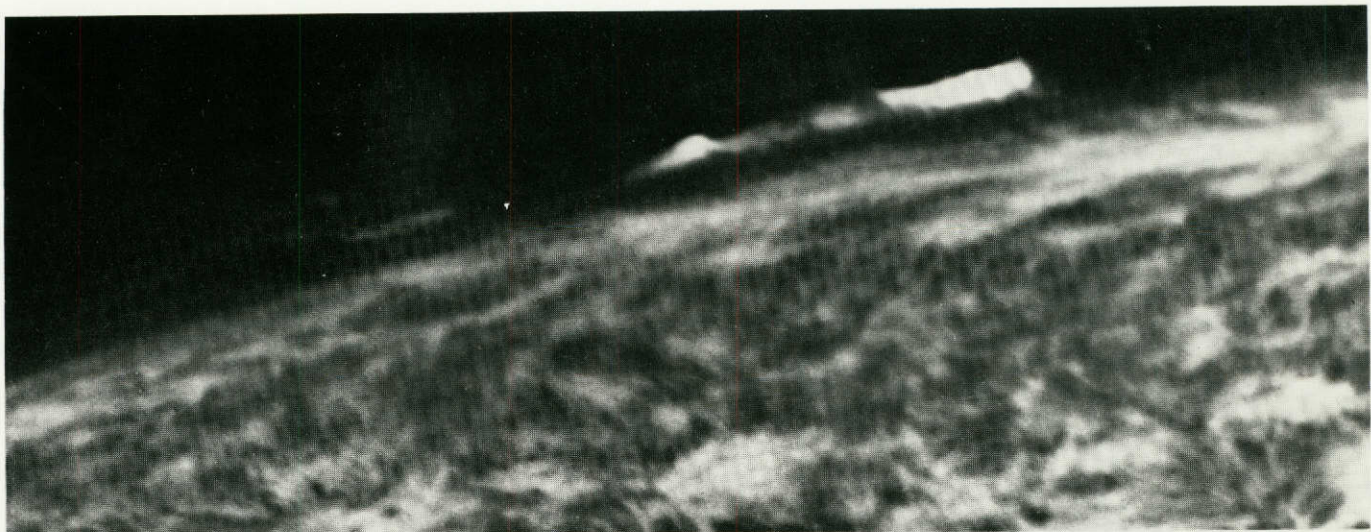
Illustrations of fibril crossing, and a sketch of the model.

and large scale magnetic patterns suggest that the large scale magnetic patterns are regular and steep gradients are localized in the neighborhood of spots, which anchor twisted force-free configurations. Therefore, we consider that fibril "b" starts at the spot, rises into a force-free region, and connects far away: it is hardly affected by the flow. The end of fibril "a" that goes back into the photosphere is carried along by the flow around the spot and is drawn under fibril "b", resulting in fibril crossing. The magnetic configuration is a rapid spatial change of  $B$ , but there is no point with zero field strength.

Another example of fibril crossing is given in Figure 7c, d on the 22nd at 20:20:00. A flare starts at 20:22, with a brightening of the region shown by the arrow and helical uncoiling motions. The final situation is shown at 20:36:25. An earlier flare (20:06:24, Figure 1e) shows the twisted fibrils in the erupting flare. It shows:

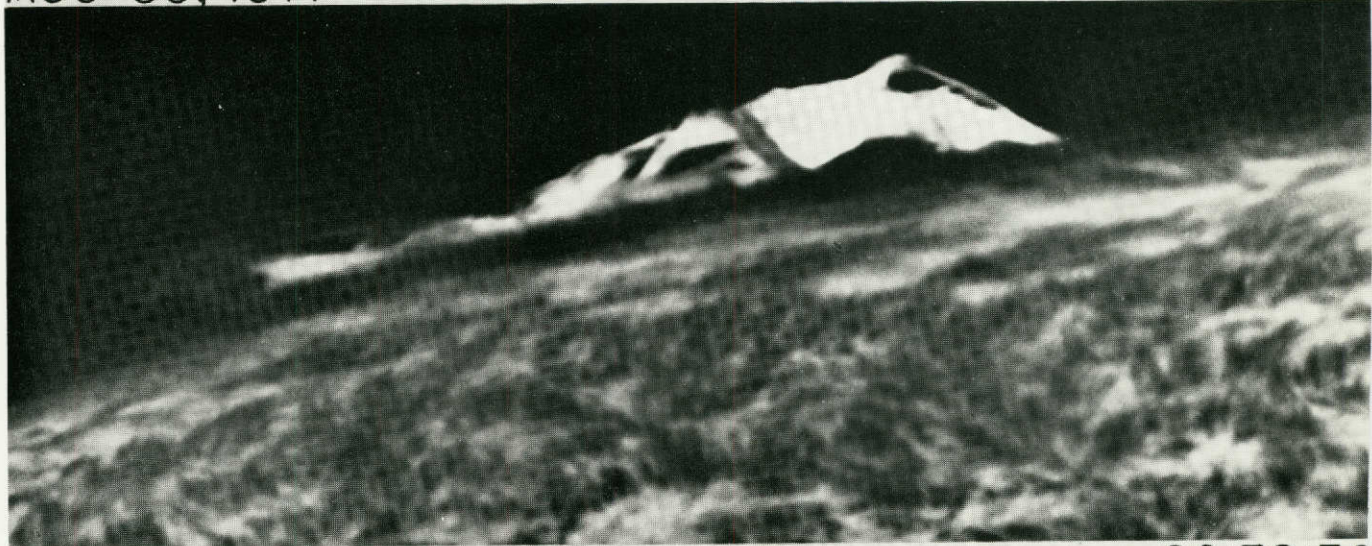
- a large fan of escaping field lines providing a wide path for the escape of hot plasma into the corona (there was a type III burst),
- a more direct connection of magnetic field lines than before the flare.

Crossed fibrils as a possible location for flares are mentioned by A. B. Severny (1960). We have found them to be commonly connected with flare occurrence. Much of the field twisting in this case occurred in the small area just ahead of spot 2; the examples we show are the outer, scaled-



AUG 30, 1971

20:25:34



20:32:30



20:39:45

Figure 8

An eruptive limb flare, August 30.

up manifestation of what was taking place right in the penumbra.

## VI. SUBSEQUENT ACTIVITY

In the succeeding days, activity decreased in the *p* part of 11482, but flares began to occur in the extreme following part. Yet the general rule continued to hold that even small flares in the *p* part gave sizeable type III while bright flares in the following part gave none. For example a brilliant flash on the 25th at 19:22:20 gave an SFD, indicating hard x-rays. No radio was reported, not even at decimeter (probably an observational problem). But quite small brightenings with outward surging at 23:02 and 23:46 ahead of the *p* spot gave substantial type III. On the 27th, a large eruption from the *f* spot at 14:59 gave both cm and strong type III. The radio records for that event have appeared in Solar Geophysical data; the burst coincides with the  $H\alpha$  flash, which precedes the eruption by a few minutes--thus the electrons are accelerated in conjunction with the  $H\alpha$  flash, and do not escape just because of the eruption.

Finally, Figure 8 shows a handsome limb flare on August 30; it was a slow, low energy event, giving no radio emission and only soft x-rays. But it shows clearly how magnetic field lines untwist in the course of a flare.

## VII. $H\alpha$ AND K-LINE COMPARISON

During this period one 10-inch refractor fed a  $1/4 \text{ \AA}$

Zeiss filter and the second, a  $0.3 \text{ \AA}$  Halle K-line filter. Most of the K-line pictures were made at  $0.6 \text{ \AA}$  or  $1.2 \text{ \AA}$  bandpass to reduce exposure time. We examined the simultaneous films to get similarities and differences. All flares appeared simultaneous in both lines; however, the dark surges were not easily seen in K-line. Obviously, since the structure is determined by the magnetic field, every K-line feature has some corresponding  $H\alpha$  feature, and the only difference is in contrast and degree. As can be seen in Figure 4, dark fibrils are not easily seen in K, partly because they have narrow absorption profiles and are not seen in  $1.2 \text{ \AA}$  bandpass and partly because they are doubly ionized and have low opacity. For this reason, in some parts of the active region we see lower in the K-line, simply because overlying filaments and fibrils do not obscure the view. Note in Figure 4 the bright points around the spot (2) which are obscured by the tangle of penumbral fibrils. As a result, some low-lying flares are more easily seen in the K-line. Of course, as is well known, plages show up with much higher contrast in K; part of this is because the Planck function is steeper at that wavelength, part because we see higher where there is no overlying material, and, as we noted above, part because that overlying material which is dark is transparent in K. The resolution of our K picture is inferior to our  $H\alpha$  pictures because of focus difficulties and longer exposure; but we believe the K structure to be slightly coarser anyway.

### VIII. CONCLUSION

Sunspot motion has often been mentioned as a source of flare energy. We have shown how most of the flares in 11482 on August 19 to 23 were directly related to sunspot motion, and we have suggested a way in which the different angular rate of motion of the spot relative to far and near field connections produces field line crossings which may be resolved by flares. Whether or not this exact mechanism works, it is clear that something similar is occurring in front of the moving spot. The spot motion in this case is connected with its growth and the separation of the  $p$  and  $f$  portions of the dipole, hence the buoyancy of the emerging flux loop is the ultimate energy source.

We found that type III bursts in this group were intimately connected with flares in one region, that flares in other regions gave no type III. Although flares in tightly confined magnetic structures gave no type III, some flares in open structures also gave no type III, so that open field lines or the existence of a concurrent surge are not sufficient for the production of type III emitters. Time comparisons show that the type III electrons are produced concurrent with the steepest  $H\alpha$  brightness rise.

Simultaneous K-line observations show no significant difference in the appearance of flares in Ca II, K and  $H\alpha$ .

Much of the activity discussed here is included in the Big Bear 1971 Show Film.

ACKNOWLEDGEMENTS

Dr. James Warwick kindly furnished his radio data. This work was supported by NSF under GA 24015 and by NASA under *NSR* 05-002-071.

REFERENCES

- Kane, S. and Donnelly, R.F.: 1971, Astrophys. J. 164, 151.  
Ramaty, R. and Petrosian, V.: 1972, Astrophys. J. 178, 241.  
Severny, A.B.: 1960, Bulletin of Crimean Astrophysical  
Observatories 22, 12.